SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer

Engine Systems

DOE Contract: DE-EE0003303

NETL Project Manager: Ralph Nine

William de Ojeda, PhD, PE
Navistar

National Energy Technology Laboratory
Department of Energy

DOE MERIT REVIEW

WASHINGTON, D.C.

16 May, 2013

Project ID: ACE059

Program Overview

NAVISTAR Advanced Technologies

Goals and Objectives

- ✓ Demonstrate 50% improvement in freight efficiency
- ✓ Demonstrate 50% engine BTE
- ✓ Demonstrate path towards 55% engine BTE
- ✓ Provide a realistic technology demonstrator to reduce petroleum consumption in the truck market.

Timeline

Project Start: Feb 2010
Project End: April 2015 (50% complete)

Engine Barriers

Achieving 50% freight efficiency while balancing "Voice of Customer" needs
Packaging, specifically of systems such as Waste Heat Recovery
Maintaining tractor weight while adding new systems

Budget

Total Project Funding:	DOE	$37,328,933
	Prime Contractor	$51,801,146
Total Project Cost to date	DOE Funding Received	$ 20,000,000
	Prime contractor	$ 21,000,000

Partners

BOSCH, Federal Mogul, Argonne National Labs, BEHR, Wisconsin Engine Research Center

Objectives and Relevance

NAVISTAR Advanced Technologies

Goals and Objectives

1. Demonstrate 50% improvement in freight efficiency
   - 20% through Engine technologies
   - 30% through Vehicle technologies
2. Demonstrate 50% BTE on Engine Dynamometer
3. Demonstrate path towards 55% BTE

Relevance

✓ **Provide a realistic technology demonstrator** to reduce petroleum consumption in the truck market:
- → Engine technologies closely worked with the "Voice of Customer"
- → Attain a payback of less than 1 year for technology introduction
- → Focus on packaging and customer interface (key in the case of Waste Heat Recovery)

✓ **Work with Partners to develop robust products for commercial integration**:
- → High pressure common rail system (BOSCH)
- → Advanced base engine technologies for friction reduction (Federal Mogul)
- → Electrified systems such as cooling pump for advanced cooling system (BEHR).

✓ **Provide innovative solutions** for alternative fuels and clean combustion systems
- → Worked with Argonne National Labs and Wisconsin Engine Research Center
- → Provide engine demonstrator to improve engine efficiency with simplified aftertreatment system

Project Development update

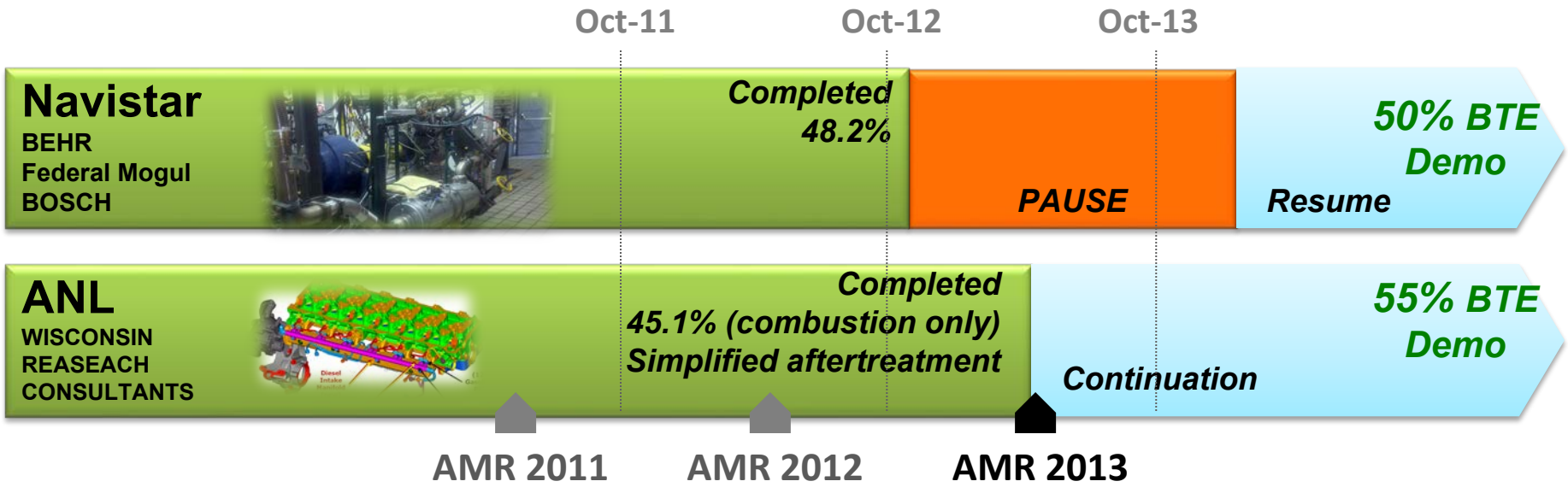
NAVISTAR Advanced Technologies

Navistar completed actions by Oct 2012

- Emissions and combustion development
- Turbocompounding
- Base engine
- VVA

Navistar entered PAUSE MODE to focus on production launches (resume in 2014)

Argonne will CONTINUE working on the 55% BTE demonstration



Engine Partnerships and completed tasks

NAVISTAR Advanced Technologies

Oct-11 Oct-12 Oct-13

Phase I | Phase II | Phase III-IV

Navistar
BEHR

- ✓ Combustion and Emissions
- ✓ Turbocompounding
- ✓ Base Engine Phase I
- ✓ VVA

50% BTE Demo

Base Engine PHASE II

Federal Mogul

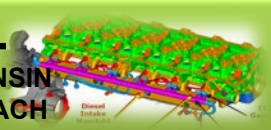
- ✓ Accessory prove out
- ✓ Friction Reduction procurement

Friction Benchmark

BOSCH

- ✓ High-injection pressure deployment
- ✓ CFD-Testing benchmarks
- ✓ High CR testing

ANL
WISCONSIN
REASEACH
CONSULTANTS



- ✓ Engine Design
- ✓ Controls deployment
- ✓ Fuel Reactivity testing

VVA
Fuels
Adv Technologies

55% BTE Demo

AMR 2011 AMR 2012 AMR 2013

Barriers and technology roadmap

NAVISTAR Advanced Technologies

Key: ✓ high confidence to contain
✸ working on improving solution

System	Barriers (challenges)	Technology Roadmap	
Engine & Vehicle	• **Cost effective** • **Robust** (controls, durable) • **Reduced weight**	Rely on analysis to select technology	✓
Engine	• **High combustion efficiency with low emissions (NOx, PM)**	Improve Fuel Injection/Air Systems Advanced Combustion Regimes	✓ ✸
Engine	• **Modest bottoming cycle efficiency** • **Simplified aftertreatment**	Advanced designs Close collaboration with suppliers Optimum integration to engine	✓ ✓ ✸
Engine	• **Non optimum fuel formulation** • **High-efficiency combustion range**	Introduce reactivity control Introduce combustion feedback Understanding of chemical kinetics	✓ ✓ ✸

Scope of Work

Technology Development and Concept Readiness

NAVISTAR Advanced Technologies

Phase II: 1 October 2011 – 30 September 2013

completed In progress

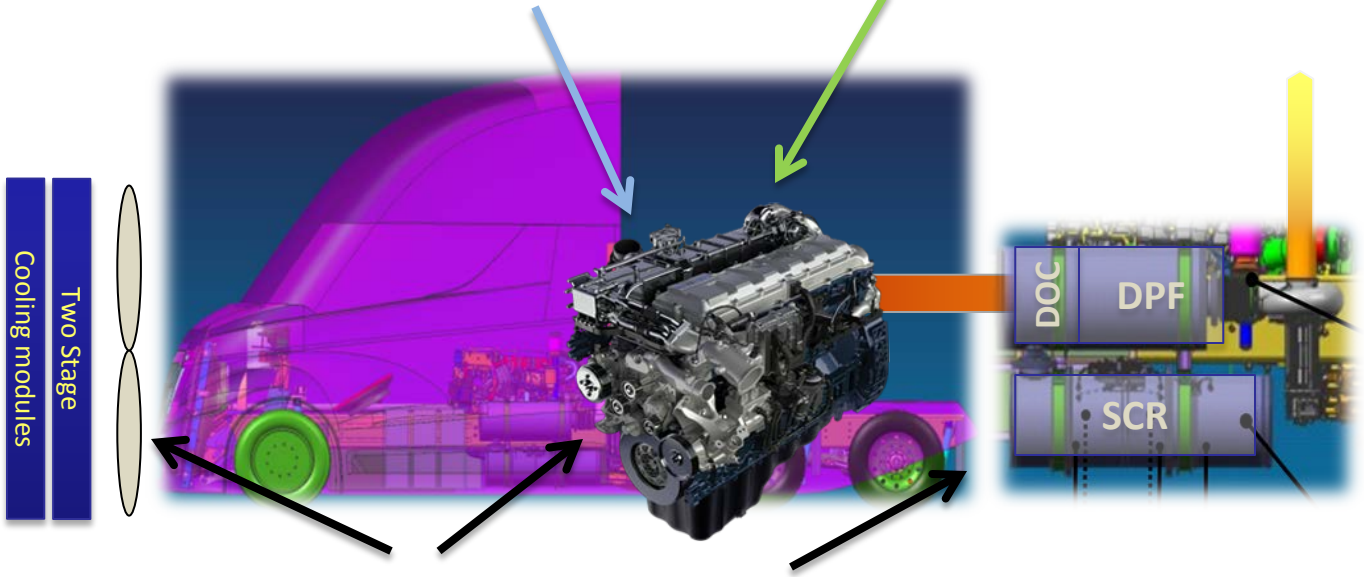
Task	Description		Status
2.1-1	**Engine and vehicle model**	Integrate engine model to vehicle	80%
2.1-2	**Advanced Diesel Combustion**		
	Fuel System to 2900bar with Comb Fbk	Complete	100%
	WHR-TUCO	Complete	100%
	VVA	Phase II: Installed and Tested 10/12 *Phase III will consider system integration*	100%
	Aftertreatment	SCR system with >80% conversion *Phase III will report on vehicle installation*	100%
	Friction reduction and electrification	Phase II procurement complete *Electrified components complete* *Remain to incorporate power cylinder tests*	80%
	Control System	Platform is built and tested	100%
2.1-3	**Fuel Reactivity Engine**		
	Lab/Engine/Controls Design and Build	Completed Engine and DAQ install	100%
	Testing of multi-fuels with Hdw level 1	Combustion characterization	80%

Approach
Technology Selection

NAVISTAR Advanced Technologies

2 Air System
Two Stage Turbocharging
Variable Valve Actuation

3 Friction-Accessories
VOP, VWP
Power Cylinder Components



4 WHR
Turbocompounding

1 Combustion
<1gNOx, <0.02gPM
HP CR Fuel injection
Increased PCP
Two stage cooling

Aftertreatment
DOC/DPF + SCR
Close coupled
Fast light-off
Low DP

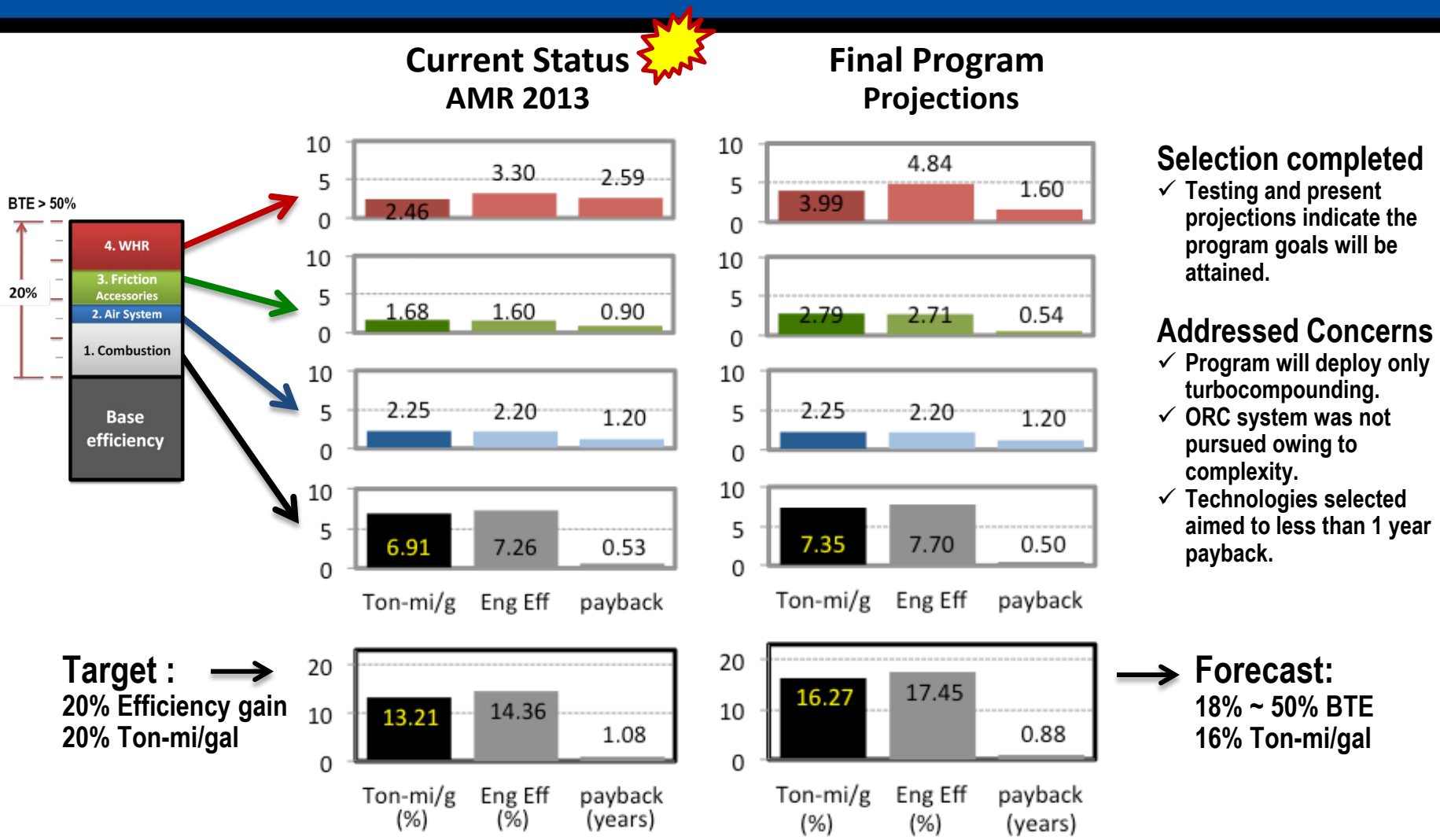
Optimize Integration Criteria

Efficiency gain **(BTE)**
Weight **(Ton-mile/gallon)**
Cost **(payback)**

Approach

Optimum Roadmap Towards 50% BTE

NAVISTAR Advanced Technologies



Selection completed

- ✓ Testing and present projections indicate the program goals will be attained.

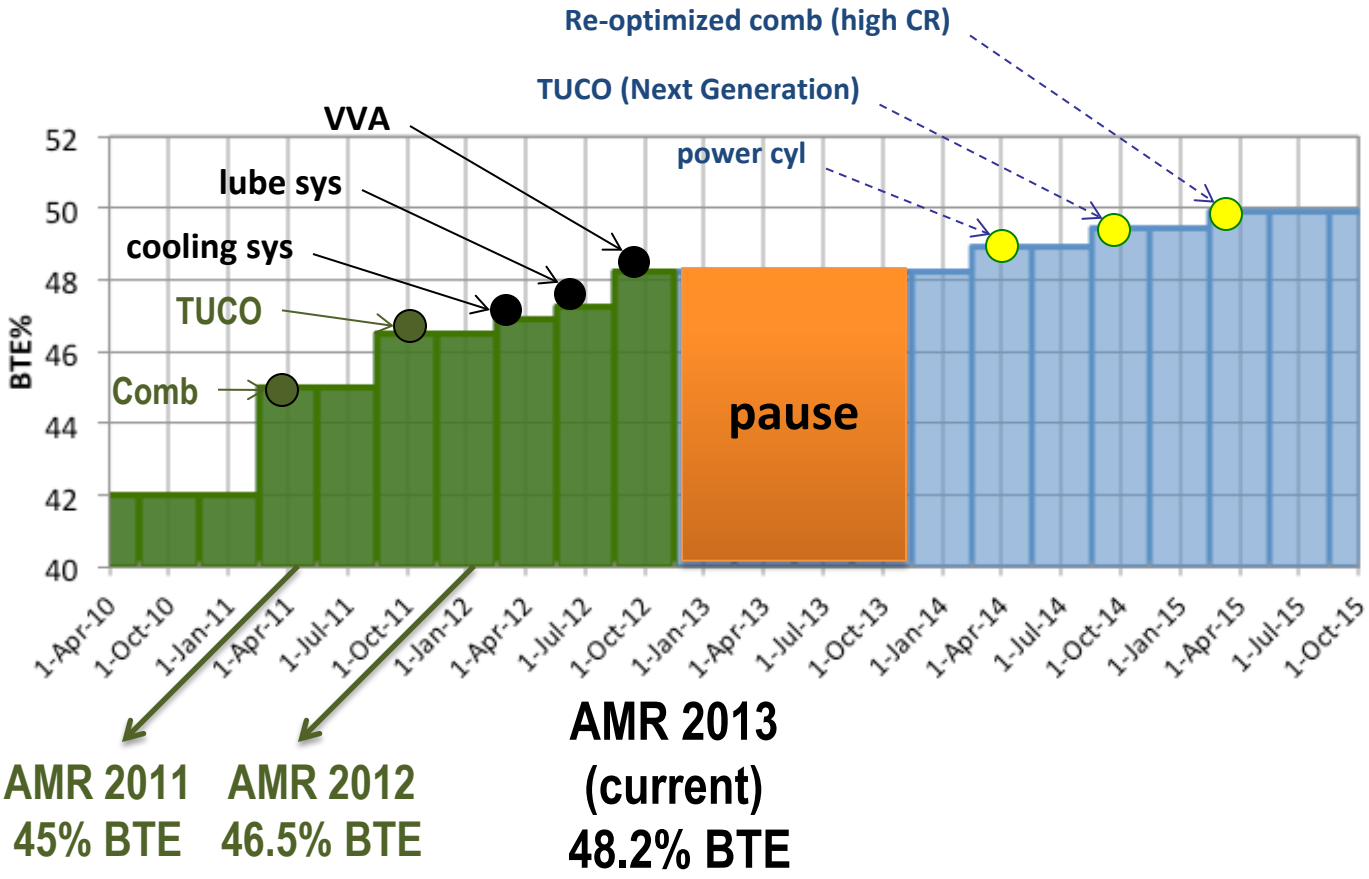
Addressed Concerns

- ✓ Program will deploy only turbocompounding.
- ✓ ORC system was not pursued owing to complexity.
- ✓ Technologies selected aimed to less than 1 year payback.

Accomplishments

Engine Dyno current efficiency at 48.2% BTE

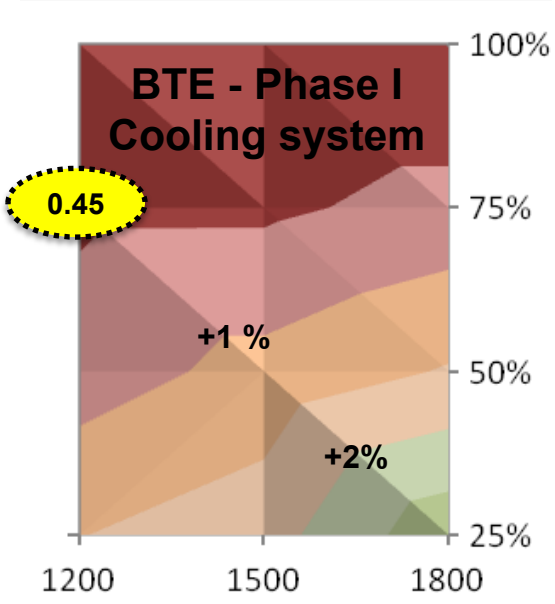
NAVISTAR Advanced Technologies

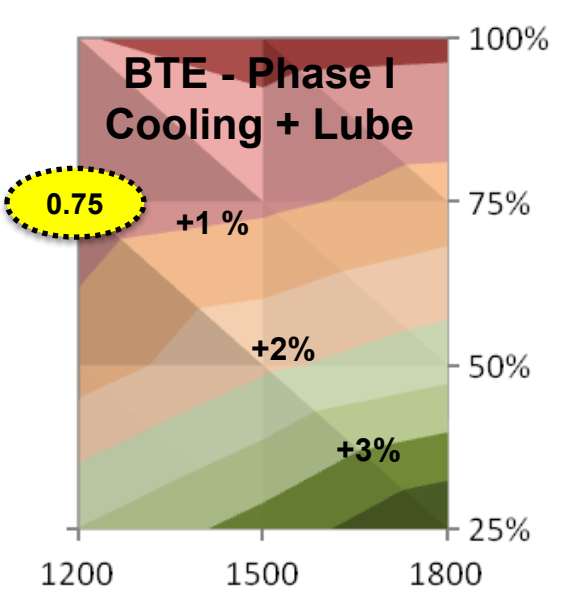


Accomplishments
Friction reduction

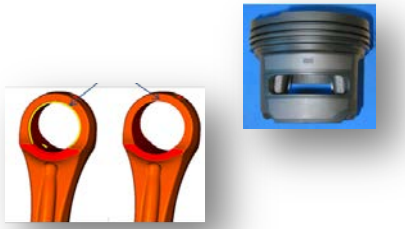
NAVISTAR Advanced Technologies

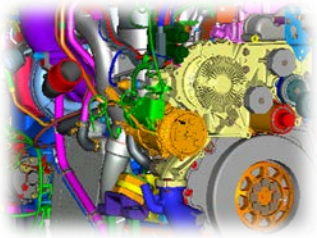
- ✓ Phase I accomplished the predicted friction reduction.
- ✓ Phase II work will complete work with introduction of Power Cylinder Components

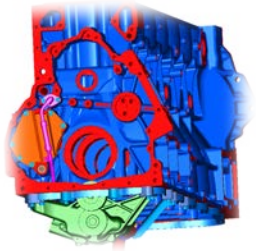


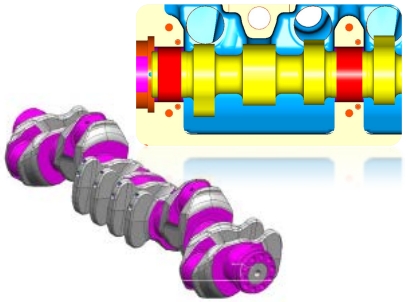


Phase II
- ✓ Power cyl comp









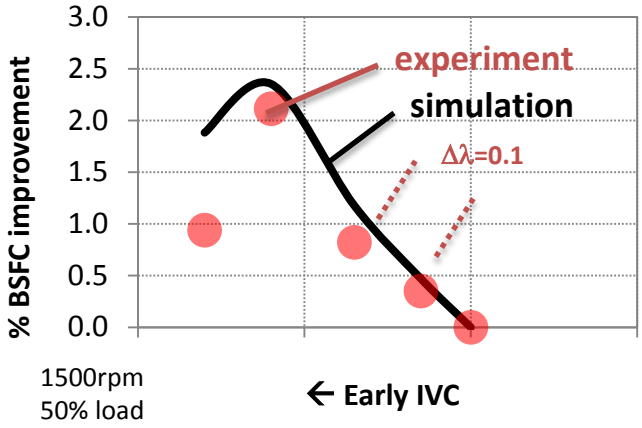
Accomplishments
Air System / VVA

NAVISTAR Advanced Technologies

- ✓ Successfully brought the engine hardware from bench testing to engine builds
- ✓ VVA system is designed to work with the two stage boost system
- ✓ First tests show the hardware aligns to early system simulations for performance enhancements

Bench testing of VVA

VVA installation on MAXXFORCE 13



Engine tests performed at constant combustion phasing

AFR and EGR decrease as IVC is advanced

Accomplishments

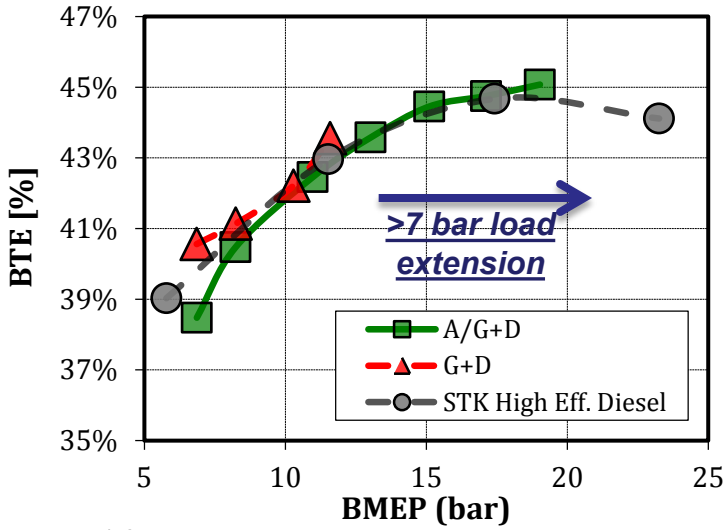
55% BTE Target with Dual Fuel Engine

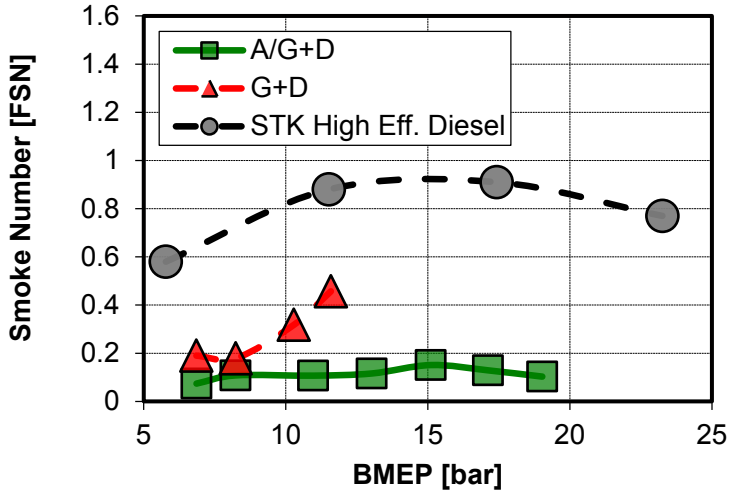
NAVISTAR Advanced Technologies

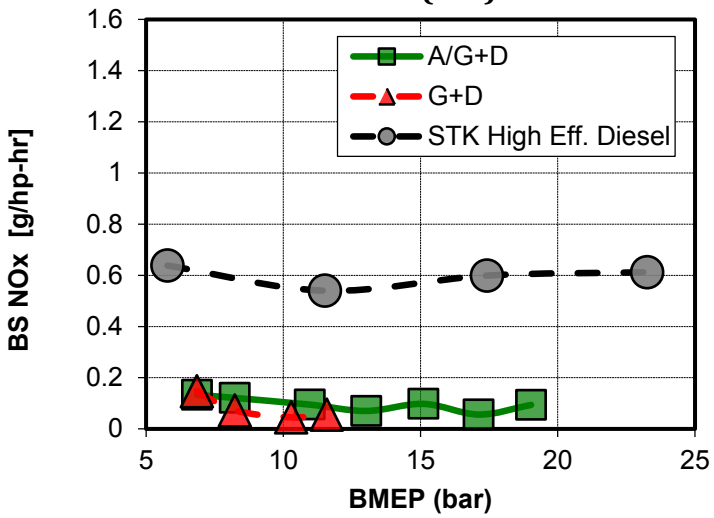
Engine Setup at Argonne:

- ✓ Alcohol/gasoline extended LTC load to **19 bar** BMEP
- ✓ Fuel-bound oxygen led to soot reduction
- ✓ improved fuel efficiency: best BTE: **45.1%**

Significant improvement on BTE with fuel reactivity at better controlled engine out emissions





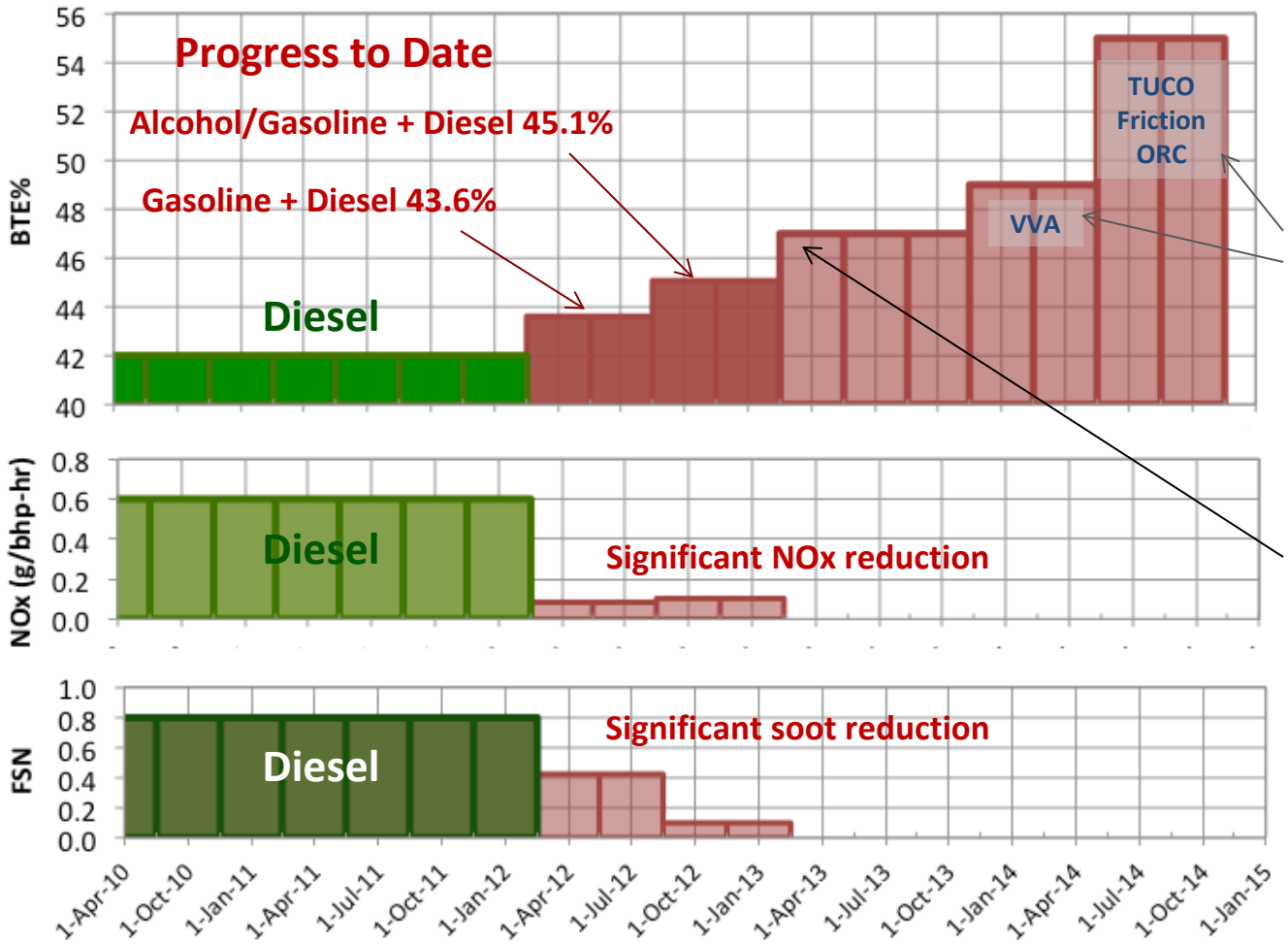


Accomplishments

Current target is 47% BTE with engine and fuels

Additional efficiency will be accounted by other technologies

NAVISTAR Advanced Technologies



55% fuel reactivity engine

Technologies from the Diesel platform

Current Target

Reactivity + CR

BTE > 47%

at NOx < 0.15gNOx

Remaining Activities for 2013

NAVISTAR Advanced Technologies

I. No activities at Navistar owing to PAUSE mode until 2014

II. Activities will continue at ARGONNE

- Complete testing of fuel reactivity matrix
- Upgrades:
  - Higher Compression Ratio
  - Installation of VVA engine
- Impact of Effective Compression ratio on load extension

Project Summary

NAVISTAR Advanced Technologies

I. To date the following technologies have been incorporated:

- ✓ **On engine combustion, leading to a growth in BTE from 42 to 45%:**
  - Extended peak cylinder pressure capability (190→220 bar)
  - Higher injection pressure (2200→2900 bar)
- ✓ **On heat recovery, leading to a further increase to 46.5%:**
  - Electrical turbo-compounding with advance air system
  - Transferred to vehicle
- ✓ **Base components, lube and cooling, were updated raising efficiency to 47.2%**
  - Power cylinder components were procured. Documentation will be postponed to 2014
- ✓ **VVA engine was commissioned and early tests indicate BTE increase to 48.2%.**

II. Advanced 55% BTE demonstrator is operational at ANL

- ✓ **Reactivity studies performed with gasoline and alcohol fuels**
  - High engine efficiencies were compatible with very reduced engine emissions
  - Study will continue with enabling features recently added such as VVA